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LOW FIELD DIPOLES FOR POLARIZED PROTON ACCELERATION

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This note makes two comments with respect to the use of the vertical Low Field Dipole array in the AGS in correcting the imperfection resonances encountered while accelerating polarized protons.

First an estimate of the correcting strength required is made using the known amount of correction required at injection for harmonics in the vicinity of the vertical tune ($\sim$8.9). The equilibrium orbit in the machine is relatively sensitive to these harmonics and hence the measurement of the orbit allows a measurement of the magnetic component.

Secondly the implications of using a particular subset of the correcting dipoles is investigated.

As part of normal injection tuning at the AGS, the 9th harmonic of the ring horizontal (and vertical) dipole field - namely a horizontal field component given by $B_x(\theta) = B_9 \cos(9\theta+\phi)$ where θ varies over 2π in making one revolution around the ring, and B_x is the field component in the horizontal plane perpendicular to the particle motion - is minimized; this to minimize the stop band around $\nu_v = 9$, and to gain aperature in the machine. One standard method for making this correction is to intentionally cause beam loss by moving the tune very close to 9, and then vary the 9th harmonic content of the low field dipole correctors to minimize the beam loss. This is usually done in a series of small adjustments. Another way to make the correction is to use the equilibrium orbit measurement provided by the 72 element PUE array, and minimize the 9th harmonic present there. The 9th seen in the orbit is proportional to that present in the magnetic field through a factor including, in addition to constants, a term $(1/(n^2-\nu^2))$ or in this case $1/(9^2-\nu^2)$. The two methods for estimating and eliminating the 9th component agree.

The PUE based method can be used for eliminating other magnetic harmonics - with a sensitivity decreasing as $(9^2-\nu^2)$ grows - and hence can be used to estimate these harmonics. This has been done for harmonics 7 through 12 which results are given below. These are the imperfection fields at these harmonics present at injection. To the extent that these result from magnet placement errors, they will scale in strength proportionally with the main ring field and hence the correction needed at some momentum P will be given by

$$(I_{corr})_{inj} \times (P/P_{inj}).$$

The table lists the number of command counts needed to correct the component, 4000 counts = 2 amps, and the current applied by a magnet located at position θ is given by I_{corr} (cos $n\theta + \phi$), where I_{corr} and ϕ are tuned to minimize the component in the PUE orbit. Errors in the PUE system itself will add in quadrature with the orbit errors; these will generally increase the estimated current required. The nulling procedure fails to be reproducible shot to shot at the level of approximately ±.1 mm which may reflect the reproducibility of the orbit measuring system.

Harominc	Correction @ injection (.65 GeV/c)		P_n=Momentum @E= $n(M_p/G)$=(.525n)	Correction @P_n (96 dipoles)	Correction @P_n (24 dipoles)
	counts	ma	GeV/c	Amps	Amps
7	450	225	3.55	1.2	4.8
8	510	255	4.1	1.6	6.4
9	210	105	4.6	.7	2.8
10	320	160	5.2	1.3	5.2
11	580	290	5.7	2.5	10
12	700	350	6.2	3.3	13.2

From this one can also make an estimate of the correction needed at any n; using 7-11, the average correction is 200 ma at injection. So in the approximation P = E, the correction required at resonance "n" is

$$I_{corr}(n) = (.2A) \times \frac{P(n)}{.65} \simeq n \times (.162) \text{ amps}$$

with 6 amps and 96 dipoles $P_{max} \simeq 20$ GeV/c

with 6 amps and 48 dipoles $P_{max} \simeq 10$ GeV/c

As a check, an attempt was made to null the orbit at 2 x P_{inj}. If the error being corrected were proportional to momentum, as assumed above, the correction required should double. The results were: for the 8^{th}, an increase by the factor (2.1); for the 9^{th} (1.5); and for the 10^{th} (1.6).

The second subject, closely related to the first, is the effect of using a smaller array of dipoles to do the correction, in particular using only dipoles at #4 and #16 straight sections in each super period. Assume one has N correction dipoles located at θ_i, i = 1, N. Assume the cosine part of the nth harmonic correction is applied by powering each dipole to a current given by $I_{max}(\cos(n\theta_i)$. Define $\theta = 0$ at the L-20 straight section. Then the harmonics the beam will see are proportional to

$$C_m = \sum_{i=1}^{N} \cos m\theta_i \cos n\theta_i \text{ for the mth cosine harmonic}$$

or

$$S_m = \sum_{i=1}^{N} \sin m\theta_i \cos n\theta_i \text{ for the mth sine harmonic}$$

For reasonably uniform correction magnet distributions, and harmonics whose phase is not a multiple of the distribution structure these terms are approximately given by

$$C_m = \begin{cases} 0 & m \neq n \\ N/2 & m = n \end{cases}$$
$$S_m = 0 \quad \forall m$$

which of course gives the obvious conclusion that in this limit the correction derived is proportional to the number of magnets powered. To look into the particular case of the AGS with 4's and 16's powered, these sums were evaluated. The result for most harmonics is as listed above with serious deviations when correction periodicity matches magnet periodicity. The table below gives a sample of these unusual strengths if the normal formula for powering the magnet array is applied, where 1 is the normal result.

harmonic	normal terms sine strength	cosine strength
6	.7	1.3
12	1.8	.2
18	1.8	.2
24	.7	1.3
30	0	2
36	.7	1.3
	cross terms	
(12-n)	0	.3
(12+n)	.3	.3
24-n	.8	0
36-n	.8	0
48-n	0	.3

Notice for example that in this approximation a sine term at $n = 30$ ($P \simeq 15.7$ GeV/c) cannot be generated. This occurs since $m = 30$ corresponds to a wave length of (240 AGS ring magnets)/30 = 8 magnets, which crosses zero at 4, 8, 12, 16, 20 and hence at both of our correctors. Incidentally going to 96 correctors means this problem doesn't occur at this total cancellation level until $n = 60$ and hence is not a problem. One could also reduce it with 24 correctors by removing the superperiod periodicity.

In conclusion then, the 24 magnet situation and correction technique has two implications for resonance correction. Firstly measurements at injection suggest that the current available may well be insufficient by 6 GeV/c. Secondly if this proves overly pessimistic, certain resonances will be hard to correct just because of the periodicity of the array - for example the cosine component at $n = 12$, $p = 6.2$ GeV/c will require five times the normal current to have the normal effect.

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